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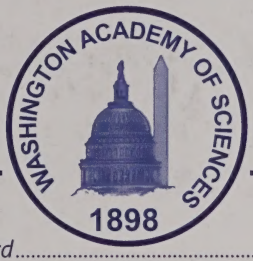

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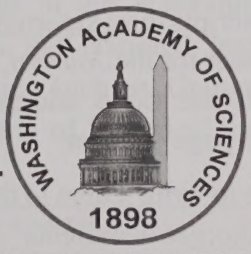

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EDITOR'S COMMENTS

Presenting the 2021 spring issue of the *Journal of the Washington Academy of Sciences*.

There are four papers in this issue plus one interesting Science Bite. They range from astronomy to risk management with a nice nod to quantum mechanics and Doppler shifts at sea. .

There is no science bite this issue. Please consider submitting short (typically one page) papers on an interesting tidbit in science. There are a lot of interesting tidbits out there. Every science field has them. They sit in your brain ready to share. We all want to learn about things in fields other than our own. So pile them up and send them in.

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Please remain safe and healthy in this time of pandemic.

Sethanne Howard

Journal of the Washington Academy of Sciences

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Spiral Galaxies When Disks Dominate their Halos (using Arm Pitches and Rotation Curves)

G.G. Byrd and S. Howard

U. Alabama and UISNO/retired

Abstract

Spiral galaxies' disk dynamics are usually considered to be dominated by more massive dark matter halos, particularly if their rotation curves, V, are flat relative to radius, r. Disk surface mass density as a function of r and its importance relative to its halo is derived from the density wave arms' winding pitch i and variable V. Results are obtained for examples with flat V and log arms of multiplicity m. The density wave disk importance relative to the halo is the ratio $F_{D/H}=F_D / F_H$ where $F_D= 4 \tan i /m$ and $F_H=1- F_D$. For the tightly wound NGC 7217 with small i, the disk is unimportant relative to the halo, fitting expectations. For less tight M51 the disk is comparable to the halo, reasonable. But for the looser M100, the density wave disk is ≈ 2 times the halo. For the still looser M101 the disk is ≈ 3 times the halo. For the loosest, NGGC 3198, the disk appears to totally dominate the halo. This sequence of progressively more important disks challenges the commonly accepted preeminence of spiral galaxies' halos over their disks.

Introduction

IT IS COMMONLY ACCEPTED that spiral (S) type galaxies' disk dynamics are usually dominated by more massive dark matter halos, particularly if their rotation curves (V) relative to radius (r) are flat well beyond the visible disk. As reviewed by Byrd and Valtonen (2020), this was first detected at 21 cm, well beyond the M31 visible disk as shown in Figure 1 (Whitehurst and Roberts 1972 and Roberts and Whitehurst 1975). Later, Bosma (1978) and Rubin et al (1978) observed extended flat curves optically for a number of Sa-Sc galaxies supporting the interpretation that the outer flat V is generated by a more spherical halo which dominates the dynamics. It is argued that a disk dense enough to solely create the flat curve would be unstable.

After initial acceptance there were some doubts as reviewed by Pfenniger (2000) who also found that simulation models containing certain massive disk components can be well behaved. Here we show via observation and dynamical theory that some S galaxies are disk dominated rather than halo dominated over their arm regions (even with flat rotation curves).

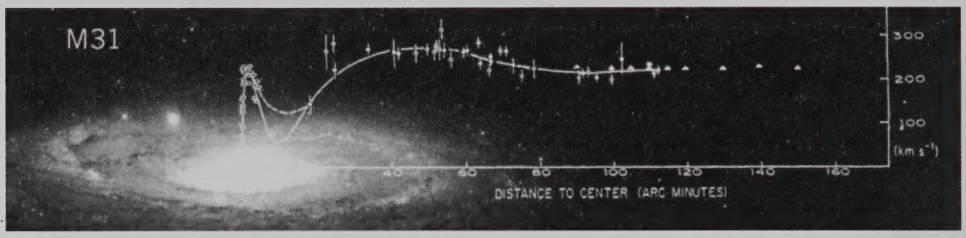

Figure 1. Superposed rotation curves on M31. Inner visual curve from Vera Rubin and 21 cm from Whitehurst and Roberts (1972) and Roberts and Whitehurst (1975). Beyond the visible disk, the flat 21 cm curve extends at least 34 kpc! Figure permission from Mort Roberts.

Arm Properties

Danver (1942) fit the arms in S galaxies and found logarithmic (log) arms in which the pitch (acute angle *i* with the circular arc) is constant as the arm *r* increases. Kennicutt (1981) found that log arms are very common. More sophisticated fittings have since been carried out with the arm pattern being the superposition of individual logarithmic spiral components by Considere and Athanassoula (1988). They found that the two-armed component is everywhere dominant.

Grand design spirals show a range of arm pitches. NGC 7217 has a tightly wound arm pair with, i= 4.8° (Buta *et al.* 1995, Figure 10) and a flat V (Kalnajs 1983). Elmegreen *et al.* (1989) fit log spirals to arm patterns and obtained 16°, 18°, and 15° respectively in the disks of M81 (NGC3031), M100 (NGC4321) and M51 (NGC5194). Honig and Reid, (2015, Figure 5) examined HII regions in M101 (NGC4321) to trace a two arm pattern whose i =20°. Going steeper, NGC 3198's arms have i = 30.0± 6.7° (Ferrarese 2002). Again, all have flat rotation curves over their density wave regions.

M51 has log arms in the main part of the disk. However, the arms near the disk edge are instead winding tidal arms due to a past companion passage (Howard and Byrd 1990 or Byrd 1995). We will discuss just type S galaxies, not strongly barred SB galaxies. In SBs arms or rings may be a forced periodic orbit pattern imposed by the bar. This pattern can also be used to estimate disk surface mass density, μ_D and mass-to-light ratio (Byrd et al. 2006).

Notation and Definitions

We derive the μ_D for the disks of spiral galaxies as a function of r as well as disk mass importance relative to its halo using the spiral arm's i and

V. The disk μ_D and disk/halo calculations are for disk regions where the arms are a classical grand design density wave pattern as proposed and developed by Lindblad (1960), Lin and Shu (1966) and Lin, Yuan, and Shu (1969).

At each point in the arm r typically increases with increasing azimuthal angle, φ, in the disk. The rotation curve is V. The orbital angular rate ($\Omega = V/r$) declines with r. For classical density waves, the arms turn with angular rate pattern speed, $\Omega_{p.} = V/r_{CR}$ where r_{CR} is the CR radius. The arm multiplicity is denoted by m for the single m=1 or the m = 2 arm pair etc. The wave number, k, wavelength, λ, and, i, have definitions given by:

$$|k| = \frac{m}{r \tan i} \tag{1}$$

$$\tan i = \frac{\Delta r}{\Delta \phi r} = \frac{2\pi}{\lambda}. \tag{2}$$

Disk Surface Density Calculation

We now calculate μ_D. The dispersion relation provides a condition for stability determined by the competing self-gravity of μ_D, velocity dispersion, a, and orbital angular rate, $\Omega = V/r$, and the shear. The density wave dispersion relation is given by:

$$S = (\omega - m\Omega)^2 = \kappa^2 + k^2 a^2 - 2\pi G|k|\mu \tag{3}$$

where m is arm multiplicity (Shu 1982). Here the epicyclic frequency squared is

$$\kappa^2 = r^3 \frac{d}{dr}\left(r^4 \Omega^2\right) = 4\Omega^2 + 2r\Omega \frac{d\Omega}{dr}. \tag{4}$$

The wave frequency is

$$\omega = m\Omega_P, \tag{5}$$

where the arm pattern speed is Ω_p.

A stable oscillation condition for a density wave ω is reached where the minimum disk velocity dispersion is

$$a_{\min} = \frac{\pi G \mu_D}{\kappa} \tag{6}$$

as is given in Shu (1982) for the axisymmetric case.

What about non-axisymmetric case? By using the swing amplification approach of Toomre (1981) for *S*, Byrd (1995's eqn. 12b) obtains close to the Equation (6) expression for tilted winding arms. *S* can be described as the spring constant for oscillation of stars relative to the arm. If there is no μ_D, then pure epicyclic oscillation is left. If a stellar disk with velocity dispersion less than a minimum a_{min} is perturbed, small perturbation arms will wind up to where *S* is less than zero. Then the arm stars' oscillation is unstable to collapse "relaxation" so the velocity dispersion increases to a_{min} for *S* of zero. We add growth from an initial perturbation to collapse relaxation as part of dispersion's origin in spiral arms by Merrifield *et al* (2001).

For $a = a_{min}$ *S* is at a minimum resulting in a longer term density wave. The observed values of *m*, *i*, the angular rate, $\Omega(r)$, and the pattern speed, Ω_p , permit calculation of μ_D . We substitute Equation (6) into Equation (3) to get a quadratic equation for μ_D. There are two possible values[1] for a given $(\Omega - \Omega_p)^2$. We choose

$$\mu_D = \left(\frac{\kappa^2}{\pi G}\right)\left(\frac{r \tan i_m}{m}\right)\left[1 + \frac{m(\Omega - \Omega_P)}{\kappa}\right]. \qquad (7)$$

because inside the square bracket, when Ω declines with respect to radius, the second term is positive inside CR and negative outside. Thus the surface density declines with radius. The equivalent equation is derived by Shu (1982).

At *CR*, where $\Omega = \Omega_p$, the second term in the square bracket is zero, so Equation (7) is close to that derived for winding arms at *CR* by Byrd (1995):

$$\mu_D = \left(\frac{e\kappa^2}{2\pi G}\right)\left(\frac{r \tan i_m}{m}\right). \qquad (8)$$

The above derivation of Equation (7) uses only the *i* of the spiral arms and the disk *V* which can vary with radius. While we will assume a flat *V* and constant *i* for the latter parts of this article, we emphasize that Equation (7) has been applied to NGC 4622 which definitely has a non-flat rotation curve (Byrd and Howard 2019).

[1] A quadratic equation typically has two solutions.

Disk Importance Relative to Halo

Now we expand and generalize Equation (7) by adding the concept of a halo and removing the need to know the CR. We derive the importance of an S galaxy's disk mass relative to its halo using its observed constant i and flat V. We do the calculation for examples of S galaxies with flat rotation curves over their density wave regions.

By substituting $\Omega = V/r$ and $\kappa^2 = 2\ V^2/r^2$ into Equation (7), the disk surface density for a flat rotation curve is

$$\mu_{D,V} = 2\left(\frac{V^2}{\pi G}\right)\left(\frac{\tan i_m}{mr}\right)\left[1+\frac{m(1-r/r_{CR})}{\sqrt{2}}\right]. \tag{9}$$

We will compare the disk to a spherical flat rotation curve halo whose mass interior to a radius is

$$M_{H<r} = \left(\frac{V^2}{G}\right)r. \tag{10}$$

The inner and outer Lindblad resonance radii of the arms are,

$$r_{ILR} = r_{CR}\left(1-m/\sqrt{2}\right) \text{ and } r_{OLR} = r_{CR}\left(1+m/\sqrt{2}\right). \tag{11}$$

Donner and Thomasson (1994) demonstrated that arms reach these density wave radial limits in their disk galaxy simulations.

Substituting, simplifying, and integrating Equation (9), we get the disk mass, $M_{D,V}$ between the *ILR* and *OLR* of the density wave,

$$M_{D,V} = \int 2\pi\mu r dr = \left(\frac{4V^2}{G}\right)\left(\frac{\tan i_m}{mr}\right)\left(1+\frac{m}{\sqrt{2}}\right)(r_{OLR}-r_{ILR}) - m\frac{(r_{OLR}-r_{ILR})(r_{OLR}+r_{ILR})}{2\sqrt{2}c_{CR}}. \tag{12}$$

The halo mass between the *ILR* and *OLR* is

$$M_{100\%,H} = \left(\frac{V^2}{G}\right)(r_{OLR}-r_{ILR}). \tag{13}$$

We divide the actual disk mass, $M_{D,V}$, by $M_{100\%,H}$ to obtain the mass ratio, F_D, of the actual disk to a full 100% halo for the density wave region as

$$F_D = 4\tan i/m. \tag{14}$$

The halo minus disk value is $F_H = 1 - F_D$. The disk compared to the actual halo is $F_{DH} = F_D / F_H$.

Using Equation (14), for our example galaxies, the 4.8° pitch of NGC 7217's arm pair indicates $F_D \approx 0.13$, a disk much less than the halo. The 15° pitch of the M51 log arm pair indicates $F_D \approx 0.54$, a disk comparable to the halo. Figure 2 compares a simulation with $F_D \approx 0.5$ to a photo of M51. While the simulation does well to simulate the density wave, effects of particle statistics and softening need to be taken into account for more tightly wound cases. Softening can be equivalent to as much as two times a_{min} in simulations like Figure 2 (Byrd 1995).

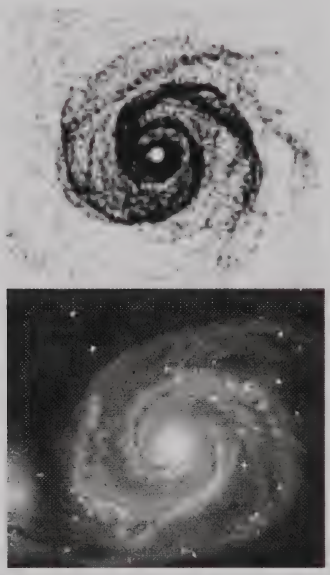

Figure 2. Simulation with $F_D = 0.5$ compared to an image of the M51 whose log arm pair whose 15° pitch indicates $F_D \approx 0.54$. Image courtesy of William Keel, University of Alabama. The companion on the lower left is far behind the disk plane, and perturbed the disk in the distant past (Byrd and Howard 1990).

The disk can be more important than the halo. For M100 the 18° pitch indicates $F_D \approx 0.63$, two times larger than the halo. The 20° pitch of M101 indicates by Equation (13) that $F_D \approx 0.73$, three times the halo. For our steepest example, NGC 3198, the 30.0± 6.7° pitch gives $F_D \approx 1.15$! Of course, F_D cannot be greater than one. The lower 23.3° value gives a more physical $F_D \approx 0.86$, still six times the role of the halo. See Figure 3 for an image of this low-halo galaxy. These last two spirals are in a sequence of progressively more important disks in our examples, challenging the overall

preeminence of the halo over the disk. The observation of few if any Sc galaxies steeper than NGC 3198's pitch is explained.

Figure 3. NGC 3198, a no-halo disk galaxy?

Conclusions

We derive how to calculate the surface mass density of the disks of spiral galaxies as a function of radius as well as the disk mass importance relative to its halo. The derivation uses only the degree of arm winding tightness or looseness along with the rotation curve for the estimates. We obtain equations both for the case of a non-linear rotation curve as well as for the common flat one.

The disk to the halo ratio is obtained over the density wave arm pattern region for example spirals with flat rotation curves. For the tightly wound NGC7217 we find the disk is much less important than the halo over the spiral arm region. For the intermediately wound M51 we find the disk to be comparable to the halo in mass over the disk arm region. For the looser armed M100 we find the disk to be twice the halo. For the loosest M101 the disk evidently dominates by about a factor of three.

For our steepest example, NGGC 3198, the disk appears to totally dominate the halo. Even with the approximations, this example sequence of progressively more important disks challenges the commonly accepted preeminence of spiral galaxies' halos over their disks.

Our results provide a starting point for more informed investigations *e.g.* of halo versus disk dark matter for different galaxy Hubble types. In another example, it has been found observationally that there is an anti-correlation between the central black hole mass and arm inclination in spiral galaxies. Smaller arm pitches are correlated with more massive central black holes (Seiger *et al.* 2008, Berrier *et al.* 2013a, b, Savchenko and Reshetnikov 2013). A physical connection of low disk mass (relative to halo) with central black holes is suggested.

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Bio

Gene Byrd (B.S Texas A&M Univ. 1968; PhD 1974 the Univ. of Texas) is a Professor of Astronomy (emeritus) at the Univ. of Alabama. He studies the dynamics of galaxies, discovering the pattern in NGC4622, which, counter-intuitively, has inner and outer spiral arms winding in opposite directions See https://www.researchgate.net/profile/Gene_Byrd2 .

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Quantum Entanglement and the Mysterious Bell's Inequality

Joe G. Foreman
Chapman U. East

Abstract

The entanglement aspect of quantum mechanics remains mysterious and controversial, although by now there are many examples of entanglement. Bell's experiment is the prototype example and illustrates the situation in a straight forward manner. This article attempts to explain Bell's experiment in a rigorous manner using only high school level mathematics (which doesn't mean that it is easy to understand). This article is for a person who is at least familiar with the popular accounts of quantum mechanics and entanglement, and such things as: the Copenhagen interpretation of quantum mechanics, the double slit experiments, Schrödinger's Cat, collapse of the wave function, the Heisenberg uncertainty principle, and Einstein's phrase, "spooky action at a distance"[1]. This article is also for the non-specialist physicist or perhaps interested thinker about physics who has questions about Bell's inequality.

Introduction

THE LITERATURE BOTH POPULAR AND TECHNICAL on the subject is vast so only a slight introduction is given here. Questions and debates about the meaning of quantum mechanics (QM) go back to the earliest days of the subject (Gamow, 1985), Prominent among those in the discussion were Einstein and Bohr at the 1927 Solvay conference. Einstein was concerned with the collapse of the wave function which implied actions at faster than the speed of light. Bohr seems to have carried the day in the discussion at the 1927 conference. Although no one seems to be able to encapsulate the Bohr theory which he called "complementarity". Another highlight in this history is the EPR paper (Einstein, Podolsky, & Rosen, 1935). In this paper two objections to QM were presented: one had to with what was called elements of reality[2]; and the other was about nonlocality or spooky action at a distance. The elements of reality had to do with whether the particles in the experiment they proposed had some property that determined how they would behave upon detection. They made the case that if the predictions of

[1]The television show "Einstein's Quantum Riddle" is a good start to this popular literature (NOVA-PBS, 2019)

[2] Laloe, 2012 has a good discussion of the elements of reality

QM are correct then QM was incomplete. There seems to be some misunderstanding about this paper, but who can argue that QM might become more complete? The next historical highlight was the publication of Bell's paper (Bell, 1966), which proposed a modified version of the EPR experiment. This paper was pretty much ignored at the time until experiments were performed which galvanized physics and led to ever more convincing experiments (Kaiser, 2011).

Outline of Approach

In this paper the mathematics is simplified by dealing with the experiments using light instead of spin 1/2 particles as used by Bell in his papers, and by addressing probabilities instead of correlations. Generally several lectures in introduction quantum mechanics deal with the mathematics of spin 1/2 particles. We avoid this problem. Most modern experiments work with light (and photons) rather that spin 1/2 particles. This has several advantages including that many more trials may be performed with light than with spin 1/2 particles. We also deal with the Wigner's version (Wigner, 1970) of Bell's theory, which deals with probabilities rather than correlations. Using photon and probabilities simplifies the mathematics and the understanding. The Wigner approach is equivalent to the Bell approach, but easier to understand. A good discussion of this is in Mandl (1993).

Bell's theorem is that local hidden variables[3] do not explain the observed probabilities (or correlations). The proof of Bell's theorem as presented by Bell is based on an inequality which has caused many to question Bell's conclusions[4]. In the following sections it is shown how this inequality is just part of the relationship generated by the assumption of hidden variables.

[3] Hidden variables involve the proposition that statistical models of physical systems (such as quantum mechanics) are inherently incomplete, and that the apparent randomness of a system depends not on collapsing wave functions, but rather due to unseen or unmeasurable (and thus "hidden") variables.

[4] See for example (Sica, 2017).

Perfect Devices Assumption

In the following we assume that the devices used in the experiments are perfect: perfect polarization filters, beam splitters, detectors, and down conversion. For example, when a beam of light impinges on a perfect polarization beam splitter there is no light that gets absorbed in the filter or lost in any other way; each unit of light either passes thru or is reflected. Such perfect devices do not exist. This imperfection presents a problem for the analysis of Bell's experiments. This problem is termed the loophole problem, and leads to considerable statistical analyses of many Bell trials. Such considerations are beyond the present discussion, and we assume that there is no problem. We use the term photon in the sense that it produces only a single current pulse in the detector and avoid more advanced considerations (Loudon, 2000). We are not concerned if it is the "same" input photon that passes through or is reflected with a change of polarization, rather we know that one photon goes in at one direction comes out in one of two directions, but we may continue to use the terminology of passing through or being reflected (or deviated as in the case of using calcite crystals as the PBS).

Linear Polarization of light

Fig. 1 illustrates the features of polarized light, polarizing filters, and polarization beam splitters important for understanding Bell's experiment. The polarization angle of the light beam is that direction along which the electric field oscillates in accordance Maxwell's equations. This explains the ambiguity in describing the polarization angle $\pm\pi$.

The figure illustrates a classical experiment showing a beam of light going into the first polarization beam splitter set at angle α. Note that this angular specification of the direction of polarization is redundant; any angle $\alpha \pm n\pi$, where n is an integer, specifies the same direction of polarization as does α. The proportion of light reflected versus the proportion of the light passing through the beam splitter depends on the distribution of polarization of the incoming beam. If the incoming beam is un-polarized (say the source is an incandescent bulb) half the output light is polarized at angle α, and passes thru the PBS, and the other half is polarized at angle $\tilde{\alpha} = \alpha + \pi/2$ and reflected from the PBS. If the beam is polarized at angle β as shown at entrance of the second beam splitter in the figure, then the beam that passes

through will be polarized at angle β, and its intensity will be reduced by a factor of $\cos^2(\beta-\alpha)$ from the incoming beam, and the energy that is reflected will be polarized at angle $\tilde{\beta}$ and be of intensity reduced by a factor of $\sin^2(\beta-\alpha)$. Since we are dealing with sin and cos squared any angle $\pm n\pi$ works the same in these functions. The experiment shown in these figures are classical: Maxwell's wave equations describe the situation, and no quantum mechanics is necessary for explanation of these experiments.

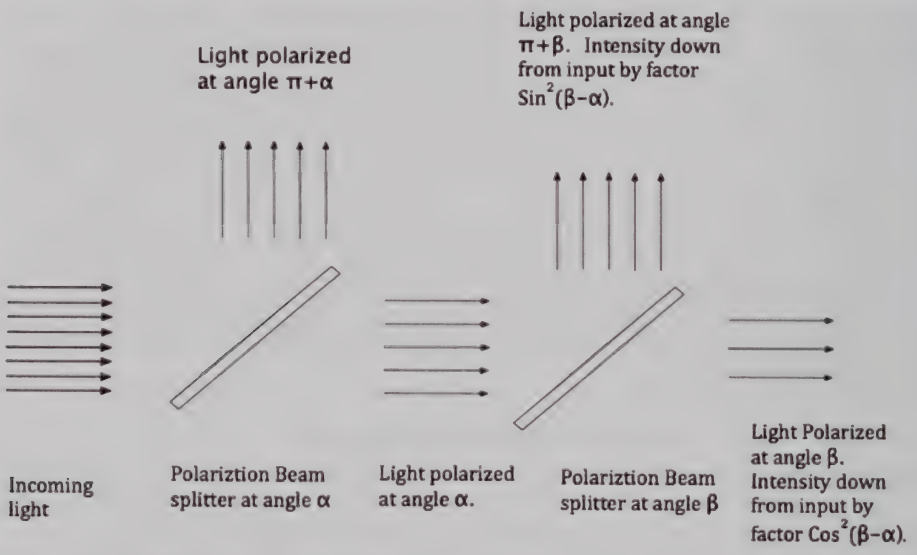
Light polarized at angle π+α
Light polarized at angle π+β. Intensity down from input by factor Sin²(β−α).
Incoming light
Polariztion Beam splitter at angle α
Light polarized at angle α.
Polariztion Beam splitter at angle β
Light Polarized at angle β. Intensity down from input by factor Cos²(β−α).

Fig 1. Portions of incident light either pass through or are reflected by polarization beam splitters.

Quantum Mechanics and Entanglement

The situation changes when the input beam is reduced to a single photon. Instead of a beam of light the intensity of the light beam is turned down to the point that there is only a single photon in a given time interval impinging on the beam splitter. We are now in the domain of quantum mechanics, and the input beam intensity split between the two outputs becomes probability of the single photon being reflected or passing through the beam splitter. Fig. 2 shows the situation. A photon polarized at angle α (meaning that it passed through a polarization filter set at angle α) must "decide" which direction it will go when it meets the polarization beam splitter at angle β. The probabilities are the same as the beam splitting

intensities: the photon goes through and becomes a photon polarized at angle β with probability $\cos^2(\beta-\alpha)$, and is reflected as a photon polarized at angle $\tilde{\beta}=\beta+\pi/2$ with probability $\sin^2(\beta-\alpha)$ as summarized in Table 1.

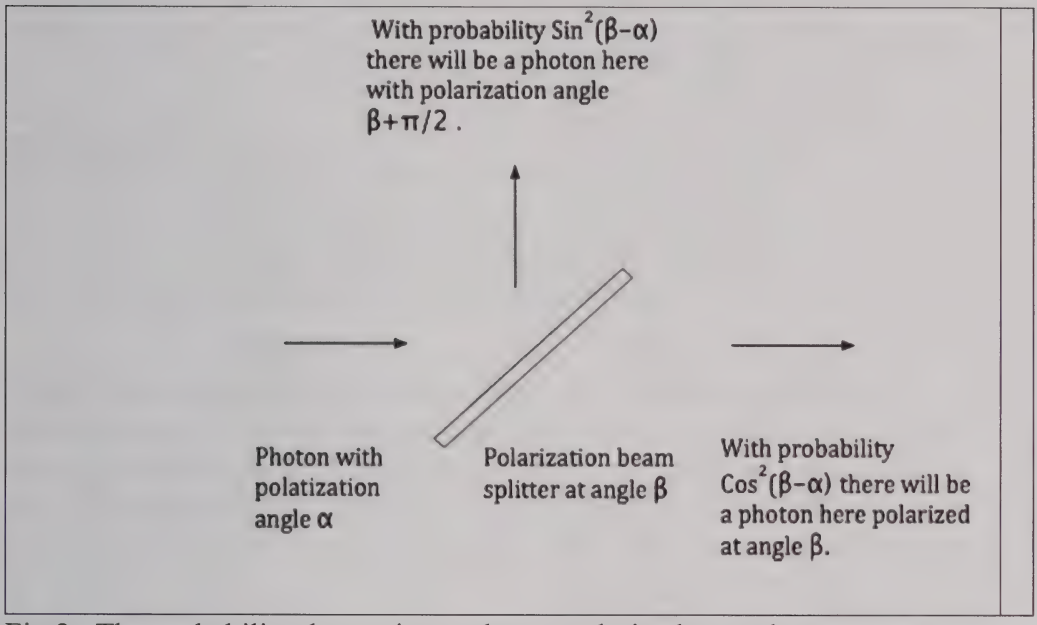
With probability Sin²(β-α) there will be a photon here with polarization angle β+π/2 .
Photon with polatization angle α
Polarization beam splitter at angle β
With probability Cos²(β-α) there will be a photon here polarized at angle β.

Fig 2. The probability that an input photon polarized at angle α passes through the polarization beam splitter set at angle $\beta(BS=\beta)$, and comes out polarized at angle β is $\cos^2(\alpha-\beta)$. The probability that the photon is reflected and comes out polarized at angle $\tilde{\beta}$ is $\sin^2(\alpha-\beta)$.

	PBS set at angle β	
Polarization State of input photon	Probability that photon passes thru the PBS exiting in state $\|\alpha\rangle$	Probability that photon is reflected by the PBS exiting in state $\|\tilde{\alpha}\rangle$
$\|\alpha\rangle$	$Cos^2(\alpha-\beta)$	$Sin^2(\alpha-\beta)$

Table 1. The results of many measurements.

In Fig. 2 what determines which way the photon goes? This is the indeterminacy question. This is one of Einstein's questions, but not his main concern. No one knows the answer to this question; all we know are the probabilities. Are there some hidden variables that determine which way a photon goes, or is it a truly "random" event? Is this an ultimate definition of random?

Another question is: does a photon come out of the PBS one way or another or is it that the photon came out both ways and we get a detection on one side or the other at the instant of collapse of the wave function which would be the standard interpretation (Copenhagen interpretation). The standard interpretation is that the wave that comes out of the polarization beam splitter is entangled and only when a measurement is made it is determined which way the photon went. This question becomes even more perplexing with entangled photon pairs in Bell's experiment.

Bell's Experiment

Fig. 3 shows the experimental arrangement for Bell's experiment. This is just a schematic; the actual experiments are more complicated and non-planer. The trigger sends a photon to the source, which then produces two entangled photons. Photon A comes out on Side A and hits the polarization beam splitter on Side A (PBS_A), which is set to angle α $(BS_A = \alpha)$. Similarly, the photon on Side B impinges on the PBS on Side B set to the angle β $(BS_B = \beta)$. The photons on each side either pass through the PBS to be detected by the detectors or are reflected to be detected by the other set of detectors shown. Actual experiments are noisy with photons detected which are not pairs. Only photons within a coincident time window are the opposite pairs.

Type 2 spontaneous parametric down conversion (SPDC) is currently the most common way of generating the entangled photons although several different sources have been used. For our purposes it does not matter because we are assuming that everything works perfectly.

To repeat: the two photons A and B that come out of the source are oppositely polarized, but neither angle of polarization of is specified. A response out of the PBS is said to be +1 if the photon passes through the PBS and -1 if the photon is reflected. This is convenient for keeping track of the responses. It is only when the photons are detected that the polarization is determined.

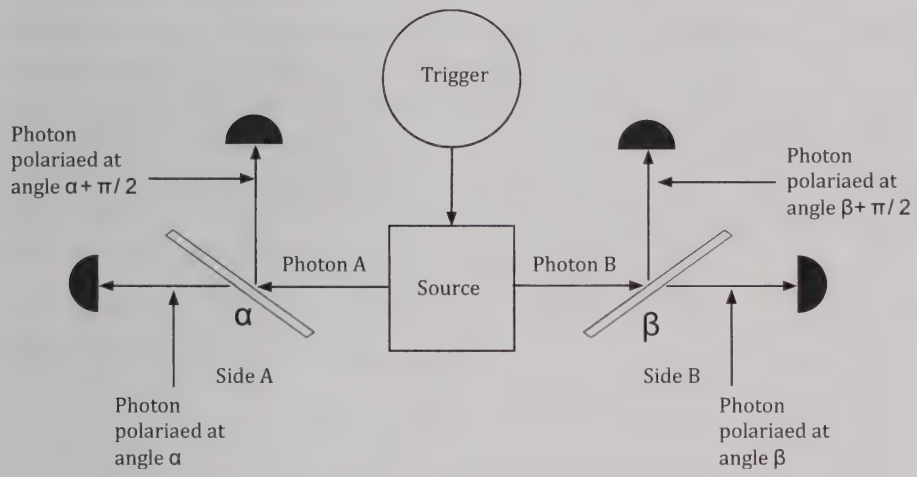

Fig. 3

The mystery comes when one supposes in an experiment the polarization angle on Side B is set to the same angle as Side A so that $\beta = \alpha$; then a photon measured on Side B will have the opposite polarization that Side A had. Similarly if the Side B is measured first a photon measured on Side A will have the opposite polarization that Side B had. It appears that information about the results of measuring the polarization of a photon on one Side is somehow transmitted to the other Side. More generally, if the photon on Side A comes out polarized at angle α, then a photon measured on Side B will be polarized at angle $\tilde{\alpha}$. Stated in another way if the photon on Side A comes out of the beam splitter in state $|\alpha\rangle$ then a coincident photon measured on Side B will behave as if it is in state $|\tilde{\alpha}\rangle$: that is to say

the probabilities will be the same as assuming that the photon on Side B is in state $|\tilde{\alpha}\rangle$. These relationships have been verified to many standard deviations by averages of many trials to verify the $\sin^2$ and $\cos^2$ probability functions. Experiments have been done where the PBS settings are made on the fly so that it would be impossible for this information to be conveyed at below the speed of light. See Whitaker (2012) for a good description of the work of Aspect *et. al.* who did the first experiments changing the angle of the PBS on the fly.

Hidden variables and Wigner's approach to a Bell type theorem

The idea of the Wigner approach is to directly assume the kind of thing that EPR suggested. This is perhaps that the output of the photon pair source is just a mixture of states rather than a quantum mechanical super position of states. What is happening is that the pair of photons coming out of the source simply come out in pairs of oppositely polarized photons and each photon has a hidden variable that indicates how it will behave in the polarization beam splitter. See Table 2.

Photon Pair Number	Probability	Photon A output Polarization	Photon B output Polarization
PP_1	η_1	α	$\tilde{\alpha}$
PP_2	η_2	$\tilde{\alpha}$	α

Table 2. The hidden variable for each of the two-photon pairs

Given this assumption for each possible measurement angle the photon "knows" which way it will go (has a hidden variable). Adopting the notation that a photon indicated by $|\alpha,+1\}$ will pass through a PBS set at angle α, and come out $|\alpha\rangle$, and a photon indicated by $|\alpha,-1\}$ will be reflected and come out $|\tilde{\alpha}\rangle$. The curly bracket notation is to indicate a photon with the indicated hidden variables may or may not be a possible photon state for more than one hidden variable. This notation indicates what polarization the photon will be in once it is measured not the state it is in before measurement. This notation was introduced to indicate that the state before measurement could be undefined as in the Copenhagen interpretation.

For easier notation we drop the numeral 1 which becomes understood. More generally a photon indicated by $|\alpha,+;\beta,-;\gamma,+\}$ that impinges on a polarization beam splitter set at angle α, β, or γ will pass through or be reflected polarized at $\alpha, \beta,$ or γ respectively. Since we are only concerned with three, we do not need to generate a notation for any of the other infinite possibilities.

For experiments in which only one angle, say α, is used in the polarization beam splitter this assumption of hidden variables is easy to fulfil as actual photon polarization state pairs. The two possible photon pairs are:

$$|\alpha\rangle_A|\tilde{\alpha}\rangle_B \text{ and } |\tilde{\alpha}\rangle_A|\alpha\rangle_B \quad (1)$$

A similar mixture of four photon pairs could account for two allowed PBS settings, but it is not possible for more than two possible angles as is to be proven. This becomes the proof of Wigner's version of the Bell theorem. Table 3 shows the eight photon pairs that are assumed to satisfy the probabilities for three allowed PBS settings.

Using Table 3 and the results shown in Table 1 we derive the equations shown in Table 4.

Photon Pair Number	Probability of occurring	Photon A hidden variable effect for PBS set at angle α, β, γ	Photon A hidden variable effect for PBS set at angle α, β, γ
1	η_1	+,+,+	-,-,-
2	η_2	+,+,-	-,-,+
3	η_3	+,-,+	-,+,-
4	η_4	+,-,-	-,+,+
5	η_5	-,+,+	+,-,-
6	η_6	-,+,-	+,-,+
7	η_7	-,-,+	+,+,-
8	η_8	-,-,-	+,+,+

Table 3. The hidden variables of the eight oppositely polarized pairs of photons that are assumed to satisfy the Bell probabilities and correlations.

BS_A[5] setting	Side A	Prob
α	+1	1/2
	-1	1/2
β	+1	1/2
	-1	1/2
γ	+1	1/2
	-1	1/2

[5] Ed. Note: Table 4 is split into two parts because of page size constraints. The left half of the six rows ae given first, and the right half of the same six rows are given second.

Conditional Probability Side B given BS settings and results of Side A measurements					
$BS_B = \alpha$		$BS_B = \beta$		$BS_B = \gamma$	
$P_B(\alpha,+)$	$P_B(\alpha,-)$	$P_B(\beta,+)$	$P_B(\beta,-)$	$P_B(\gamma,+)$	$P_B(\gamma,-)$
0	$\eta_1+\eta_2+\eta_3+\eta_4 = 1$	$\eta_3+\eta_4 = \frac{1}{2}C^2_{\alpha\beta}$	$\eta_1+\eta_2 = \frac{1}{2}S^2_{\alpha\beta}$	$\eta_2+\eta_4 = \frac{1}{2}C^2_{\alpha\gamma}$	$\eta_1+\eta_3 = \frac{1}{2}S^2_{\alpha\gamma}$
$\eta_5+\eta_6+\eta_7+\eta_8 = 1$	0	$\eta_7+\eta_8 = \frac{1}{2}S^2_{\alpha\beta}$	$\eta_5+\eta_6 = \frac{1}{2}C^2_{\alpha\beta}$	$\eta_6+\eta_8 = \frac{1}{2}S^2_{\alpha\gamma}$	$\eta_5+\eta_7 = \frac{1}{2}C^2_{\alpha\gamma}$
$\eta_5+\eta_6 = \frac{1}{2}C^2_{\alpha\beta}$	$\eta_1+\eta_2 = \frac{1}{2}S^2_{\alpha\beta}$	0	$\eta_1+\eta_2+\eta_5+\eta_6 = \frac{1}{2}$	$\eta_2+\eta_6 = \frac{1}{2}C^2_{\beta\gamma}$	$\eta_1+\eta_5 = \frac{1}{2}S^2_{\beta\gamma}$
$\eta_7+\eta_8 = \frac{1}{2}S^2_{\alpha\beta}$	$\eta_1+\eta_3 = \frac{1}{2}S^2_{\alpha\gamma}$	$\eta_3+\eta_4+\eta_7+\eta_8 = \frac{1}{2}$	0	$\eta_4+\eta_8 = \frac{1}{2}S^2_{\beta\gamma}$	$\eta_3+\eta_7 = \frac{1}{2}C^2_{\beta\gamma}$
$\eta_5+\eta_7 = \frac{1}{2}C^2_{\alpha\gamma}$	$\eta_1+\eta_3 = \frac{1}{2}S^2_{\alpha\gamma}$	$\eta_3+\eta_7 = \frac{1}{2}C^2_{\beta\gamma}$	$\eta_1+\eta_5 = \frac{1}{2}S^2_{\beta\gamma}$	0	$\eta_1+\eta_3+\eta_5+\eta_7 = \frac{1}{2}$
$\eta_6+\eta_8 = \frac{1}{2}S^2_{\alpha\gamma}$	$\eta_2+\eta_4 = \frac{1}{2}C^2_{\alpha\gamma}$	$\eta_4+\eta_8 = \frac{1}{2}S^2_{\beta\gamma}$	$\eta_2+\eta_6 = \frac{1}{2}C^2_{\beta\gamma}$	$\eta_2+\eta_4+\eta_6+\eta_8 = \frac{1}{2}$	0

Table 4. The probable outcomes for each of three settings of the polarization beam splitter on side A and side B where $S_y \sin^2\left(\theta_i-\theta_j\right)$ and $C_y = \cos^2\left(\theta_i-\theta_j\right)$ and $i, j \in \{\alpha,\beta,\gamma\}$.

As an example for these equations consider the case $BS_A = \alpha$, and $BS_B = \beta$. The conditional probability of measuring α on Side A, and β on Side B given that a detection has occurred on Side A, or a detection has occurred on Side B, and that detections have occurred on both sides is:

$$P_{\alpha,\beta}\left(+,+\middle|\text{detection on one side or the other}\right) = \cos^2\left(\alpha-\beta\right) \qquad (2)$$

Similarly, the probability of measuring α on Side A and measuring $\tilde{\beta}$ on Side B is:

$$P_{\alpha,\beta}\left(+,-\middle|\text{detection on one side or the other}\right) = \sin^2\left(\alpha-\beta\right). \qquad (3)$$

By incorporating the conditional probabilities Table 4 shows the entirety of these relations. The matrix is 6 x 6. Six equations are zero. For example:

$$P_{\alpha,\alpha}(+,+)=0. \tag{4}$$

Six elements are one sided probabilities:

$$P_A(\alpha,+),P_A(\alpha,-),P_A(\beta,+),P_A(\beta,-),P_A(\gamma,+),P_A(\gamma,-) \tag{5}$$

independent of what is measured on the other side. For example the first of these is:

$$P_A(\alpha,+)=\eta_1+\eta_2+\eta_3+\eta_4. \tag{6}$$

The probability that α is detected on Side A is the sum of the probabilities for the occurrence of photon pair PP_1, PP_2, PP_3, or PP_4. This sum is normally assumed to be 1/2. Whatever the BS setting it is equally probable that the photon will go either direction while looking at on one side. This has not always been the case for experimental results, but that turns out to make no difference in the overall proof. Equation (6) becomes

$$P_A(\alpha,+)=\eta_1+\eta_2+\eta_3+\eta_4=\frac{1}{2}. \tag{7}$$

For example, given $PBS_A=\alpha$ and $PBS_B=\beta$, Equation (2) becomes

$$P(\alpha,\beta)=\frac{1}{2}\cos^2(\alpha-\beta) \tag{8}$$

There are 24 such equations in the Table. Twelve of these equations are duplicates, and four more are linearly dependent. We finally obtain eight independent equations in the eight unknowns η_i, one of which is Equation (8). The determinate of the equations is non-zero, and thus these equations have a unique solution.

An example of one of these values is:

$$\eta_1=-\frac{1}{4}\cos^2(\alpha)+\frac{1}{4}\cos^2(\alpha-\beta)+\frac{1}{2}\cos^2(\beta)-\frac{1}{4}\sin^2(\alpha). \tag{9}$$

But η_1 has negative values for some values of α and β (as do other η_i's). Probabilities cannot be negative so there is no meaningful solution given

this constraint. This is the proof that hidden variables in the photon pair as shown in Table 3 do not explain the mystery of the apparent spooky action at distance.

Bell's proof and the inequality

One version of Bell's proof starts with the equations

$$P(\alpha,\beta)=\frac{1}{2}(\eta_3+\eta_4),\ P(\alpha,\gamma)=\frac{1}{2}(\eta_2+\eta_4),\ P(\gamma,\beta)=\frac{1}{2}(\eta_3+\eta_7). \quad (10)$$

The following inequality is clear since we assume that the probabilities η_i are non-negative:

$$\eta_3+\eta_4 \le \eta_2+\eta_4+\eta_3+\eta_7. \quad (11)$$

Now substituting the probabilities from Equation (10) and dividing out the 1/2s:

$$P(\alpha,\beta) \le P(\alpha,\gamma)+P(\gamma,\beta). \quad (12)$$

Substituting the functions of the angles from the table this inequality becomes:

$$\cos^2(\alpha-\beta) \le \cos^2(\alpha-\gamma)+\cos^2(\gamma-\beta) \quad (13)$$

The actual Bell's inequality used sines instead of cosines, but it is the same idea. Bell was dealing with spin 1/2 Particles. This inequality is not satisfied for many choices of angles, for example take $\gamma=(\alpha+\beta)/2$, and $\theta=\alpha+\beta$ then Equation (13) becomes

$$\cos^2(2\theta) \le 2\cos^2(\theta). \quad (14)$$

Fig. 4 is a plot of these functions, and shows that for many values of θ the inequality does not hold. Thus, not all the η_i are positive. A much easier proof than inverting an 8 x 8 matrix, but it obscures the reason.

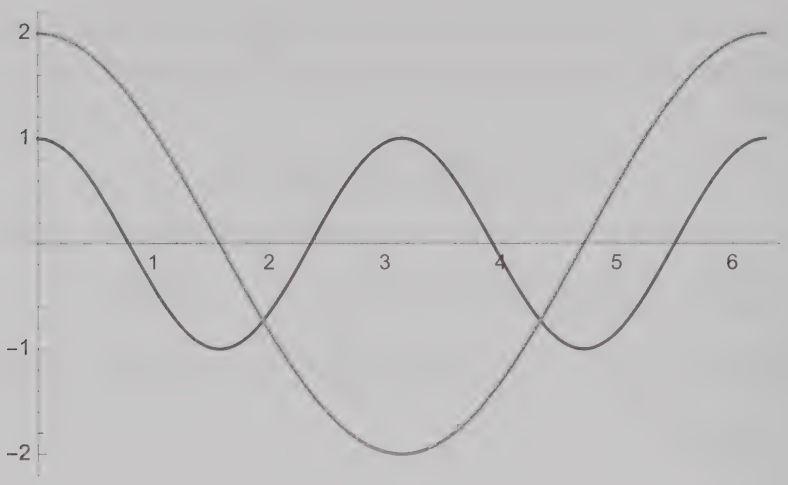

Fig. 4. The graph shows values of the angles where the inequality is not satisfied.

One strange thing about the photon pair assumption is that a detection on both sides determine the probability of the different detections had one of the PBS been set at a different angle. To see this effect use Table 4 and suppose $BS_A = \alpha$, $BS_B = \beta$, and (+,+) is measured. This was caused by either PP3 orPP4. Given that is what happened, we know that a detection of +1, which had $BS_B = \gamma$, must have been caused by PP4 and this probability is η_4. Similarly if -1 is measured on side B this would have been caused by PP3 with probability η_3.

A conceivable set of pairs of photons that would satisfy all the equations in Table 4 is shown in Table 5. The zeros indicate that there is no detection for that PBS setting. There are four photon pairs for each two-Sided PBS setting. The other photon pairs would cause only one detection within the time gate and therefore not count as an event of interest. There are no photons that behave like those in Table 5.

Photon Pair Number	Photon A hidden variable effect for PBS set at angle α, β, γ	Photon A hidden variable effect for PBS set at angle α, β, γ
1	0,+,+	0,-,-
2	0,+,-	0,-,+
3	0,-,+	0,+,-
4	0,-,-	0,+,+
5	+,0,+	-,0,-
6	+,0,-	-,0,+
7	-,0+	+,0,-
8	-,0,-	+,0,+
9	+,+,0	-,-,0
10	+,-,0	-,+,0
11	-,+,0	+,-,0
12	-,-,0	+,+,0

Table 5. A collection of oppositely polarized pairs of photons that satisfy the Bell probabilities and correlations.

What does it mean?

It means that the notion that the apparent faster than the speed of light situation cannot be explained away by a mixture of photon pairs with hidden variables (except for those unrealistic ones). Some suggestions have been made[6], but no one has been able to devise any other explanation. The only possibility seems to be quantum mechanical entanglement, but there is no proof.

The hidden variable question is a basic question in QM. It is the question discussed in connection with Fig. 2. There is no evidence that there are hidden variables, and the non-determinist aspect of this is important for quantum computing.

[6] See for example (Sica, 2021)

How all this can be encompassed into the future theories of QM and general relativity remains to be seen.

Many thanks to Louis Sica for useful conversations on this subject.

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BIO

Joe Foreman was studying physics at Johns Hopkins University during the 'shut up and calculate' days of quantum mechanics. There were few jobs in physics at that time so he switched to electrical engineering for his Ph.D. at Hopkins. He now does research in quantum mechanics and in gravitational waves, and is affiliated with Chapman University East in Burtonsville, MD.

Errors due to Doppler Shift in Measured Levels from a Moving Ship

David J. Vendittis and Paul Arveson

ABSTRACT

Standards for ship noise measurements prescribe beam aspect measurements that cover a sector of 60 degrees centered on the port or starboard. As the ship is in motion, radiated noise frequencies measured at a fixed receiver are affected by Doppler shifts. The amount of shift is usually not significant in the 1/3-octave frequency band measurements prescribed by the standards, but it can become quite significant if tones are measured in narrower bands. We illustrate that error here and suggest minimum analyzer bandwidths that should be used for narrow band measurements.

INTRODUCTION

SINCE THE 1940S several countries around the world have been conducting measurements of the radiated noise levels of navy ships. In more recent times the research community has had an increasing interest in noise from commercial cargo ships, due to concerns about the impact of high ship noise levels on marine life in the sea.

In the early days noise measurements were analyzed with analog filters that have a 1/3-octave bandwidth (spanning about 23% of the center frequency). Also, measurements were made with a vertical string of several hydrophones, in order to provide some averaging over variations caused by surface reflections and source directivity.

Based on this experience, ANSI and ISO standards for measurement of surface ship noise were developed that prescribed 1/3-octave band filters and samples spanning a long time, to provide averaging over vertical and horizontal angles of the ship's radiation [1, 2, 3]. Specifically the standards call for noise to be sampled over an azimuthal (horizontal) angle of ± 30 degrees relative to the port and starboard beam aspect. In Figure 1 this refers to the angle sector of 60 degrees centered on the starboard beam aspect as

the ship passes a fixed receiver at velocity v at a horizontal distance a at closest point of approach (CPA).

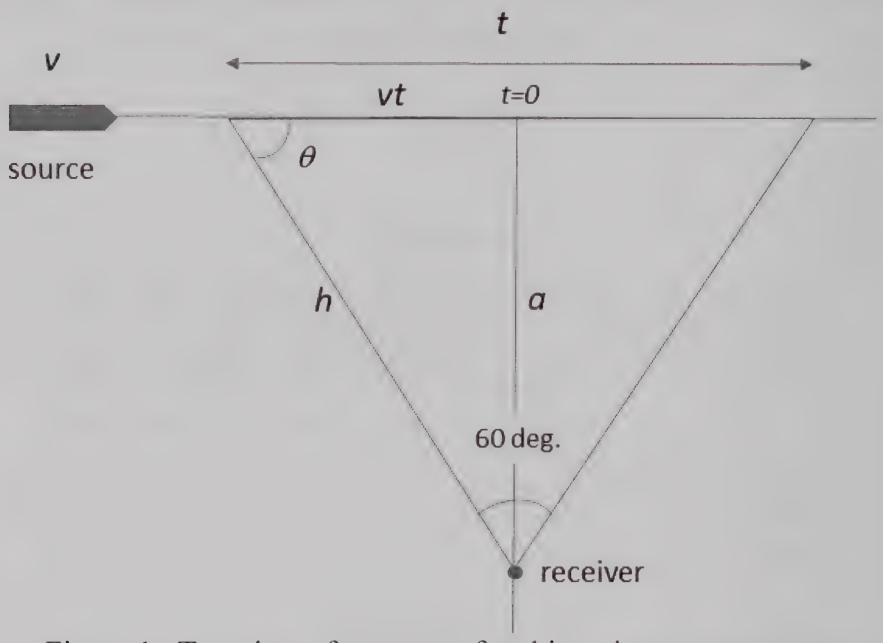

Figure 1. Top view of geometry for ship noise measurements.

By combining averages across frequency, time, and aspect angles, compliance with these standards yields relatively stable and consistent measurements of ship noise levels. However, currently, high-speed computers enable measurements to be analyzed in narrow bandwidths, such as 1 Hz "spectrum levels". This practice can result in significant errors in levels that are not seen in measurements of tones in the wide 1/3-octave bands. This article highlights one source of these errors.

ERROR DUE TO THE DOPPLER EFFECT

Ship noise typically contains a combination of wideband noise and some high-level tones, which dominate the spectrum at low frequencies. Due to the well-known Doppler principle (commonly known as the Doppler Effect), the frequencies of noise received from a moving source are shifted by a small amount. This small shift does not usually cause significant errors in measured levels of tones using 1/3-octave bands, because it will seldom shift the tone's frequency out of the wide band. But if the tone is analyzed in narrow bands (such as 1-Hz spectrum levels), the tone will not spend

much of the sample time in any band, and reductions in its measured level can be quite large. This error can be calculated. For simplicity we will do the calculation in two dimensions and neglect the depth dimension (*i.e.* multiple receivers in a vertical string of hydrophones); this is because frequency shifts for deeper receivers will be smaller than the shallow receivers.

When a source emitting a tone at frequency f moves with a velocity v, the measured frequency at a stationary receiver f_D is altered by the factor $v \cos \theta$, where θ is the angle between the source velocity vector and a line toward the receiver; this is the Doppler shift, D. Thus we have Equation (1) and Equation (2):

$$f_D = f + D, \tag{1}$$

and

$$D = f\left(v \cos\theta\right) / c \tag{2}$$

where c is the speed of sound in water.

The ship noise measurement standards prescribe samples to be acquired over a sector of 60 degrees centered at beam aspect. In this case at the start of the sample time the angle between the ship course and receiver path equals 60 degrees, so $\cos\ \theta = 0.5$. Then the Doppler shift is $f(1 + 0.5\ v/c)$ at the start and the shift is $f(1 - 0.5\ v/c)$ at the end of the sample, for a total Doppler shift of $fv / c = D_{total}$.

When a tone is sampled with a filter of bandwidth B, if $B < D_{total}$, then there will be an error in the measured levels. For a total Doppler shift, D_{total} and filter bandwidth B, the approximate error is $10 \log\left(D_{total} / B\right)$ given in dB.

As an example of the measurement errors that are introduced in narrow band analysis, Figure 2 presents calculated levels of a tone at 1 kHz as measured in 1-Hz bands at various ship speeds. The correct level is 0 dB. Erroneous reductions in levels of over 10 dB are evident.

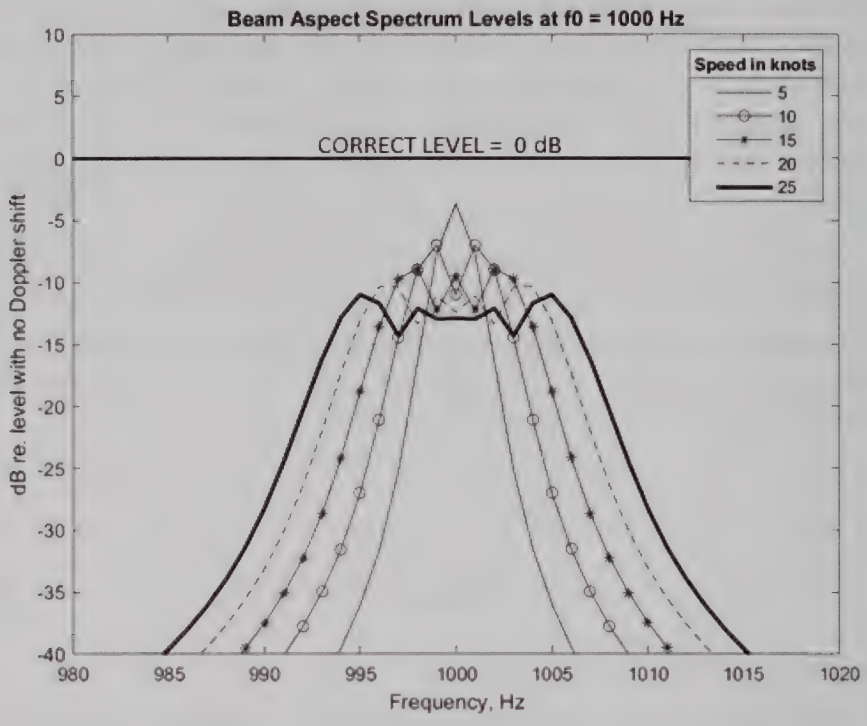

Figure 2. Calculated beam aspect 1 Hz spectrum levels of a tone at 1 kHz at various speeds.

Table 1 shows the total Doppler shifts encountered for beam aspect samples at various ship speeds (assuming sound speed = 1500 m/s).

Table 1. Total Doppler shift within a 60-degree angle sector centered on beam aspect, Hz

Speed kts. -> Freq.	5	10	15	20	25
50	.085	.17	.255	.34	.425
100	.17	.34	.51	.68	.85
200	.34	.68	1.02	1.36	1.7
500	.85	1.7	2.55	3.4	4.25
1000	1.7	3.4	5.1	6.8	8.5

CONCLUSION

Ships moving in a seaway generally encounter variable loads on the propulsion system, which causes random variations in the frequencies of machinery tones. These variations can cause errors in levels in addition to those due to Doppler shifts. As a rule of thumb, for ship speeds less than 25 knots, to reduce errors in tonal levels the analyzer bandwidth should be wider than 1% of the center frequency.

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BIO

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"RISK ANTICIPATION": AN EMERGING CONCEPT

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Occupational + Environmental Health & Medicine

Abstract

Public agencies, private enterprises, and thought leaders are often faced with hazards for which information is not yet available to conduct a proper risk assessment. The capacity of government agencies to conduct full-scale risk assessment is limited. In the political space and in policy studies, tools would be useful to identify hazards that are likely to become public issues in the near and long term, in order to ensure that public concerns are anticipated and seen to be addressed. As new risk issues emerge, it is important for prioritizing assessment and management that public agencies and the private sector assess the likelihood that an issue, such as a novel environmental hazard, will attract public attention and concern. This early step in the process of risk assessment may be called "risk anticipation". Risk anticipation requires evaluation of the characteristics of the issue that are most likely to arouse concern and is similar to prospectively analyzing the perception of risk. Two preliminary studies demonstrate that risk anticipation can be formalized and may represent a new direction for investigation in risk science. Directions for future research are outlined.

Introduction

THE ROLE OF RISK ASSESSMENT and risk management in environmental health protection or ecosystem protection is well defined and understood as a necessary preliminary to risk management. (Environmental Protection Agency, 2004; Presidential Commission, 1997) However, little attention has been given to "risk anticipation", the question of how to identify issues that are likely to emerge as social problems and will merit from risk assessment. (Smith *et al.*, 2008) Issues of concern to society (and its various publics) may not be considered to be as threatening to experts as they do to the public, because of their perceived uncertainties: this situation describes 5G technology, unexceptional trace element exposure in daily life, and "toxic contaminants" (biologically active organic compounds such as drug residues) in surface waters. Conversely, some issues that are of minor concern to the public may be perceived as underappreciated by experts: toxicity of perfluorinated chemicals and perchlorates, the fashionable use of flowers (some of which contain active toxins) in foods, and various invasive

species. The point is not the merit of these concerns or the process by which they become public issues (such as small-group activism or widespread concern) and this is not the place to argue magnitude of risk of individual issues. The point is that there is a divergence between public perception and expert opinion that may result in the public perception that an issue has been neglected or that distracts from the urgency of greater risks.

Both the theory and practice of risk communication require models of public engagement and responsiveness if they are to be complete in describing social behavior and useful in risk communication. The ability to predict which emerging issues are more likely to become social issues may also be useful for conducting future quasi-experimental studies in risk perception. The clearest and most defensible criterion would of course be the importance of the issue to human and ecosystem health, but in practice the magnitude of risk is seldom known for novel issues nor accessible to the nonexpert public. However, public confidence is based at least in part on the sense that issues the public recognizes as "important" are being addressed. Fortunately, the discipline of risk perception has identified a number of factors that can be applied for risk anticipation.

For regulatory agencies or advocacy groups, such a capability would also solve a practical problem by identifying which issues are emerging and require attention, regardless of the preliminary appearance of scientific merit? How does an agency or producer identify in advance those issues or products most likely to emerge on the public agenda as risk concerns? Put another way, where should an agency, advocate, or corporation put their energy in anticipating which issues will generate concern and from which hazards perceived risk may come to public attention?

These issues are subsumed under "hazard identification" in the US Environmental Protection Agency's risk assessment model. Neither the Canadian nor the US systems have developed a prioritization step subsumed under "hazard identification," at least in a systematic manner. In particular decision-support experts using the two models have not developed criteria for determining in advance of public action which issues are likely to require a formal risk assessment and consideration of risk management options. This is partly because the political process, the media, and new scientific developments introduce unpredictability in the regulatory agenda and typically move faster than the regulatory system can adapt. However, as new

issues emerge, it is important that public agencies (Canada, 2017) and the private sector (Schlarman, 2019) assess the probability that a hazard is likely to trigger public concern.

There are many possible threats but the majority will not prove to be substantial risks. Many of these issues will attract public attention well in advance of corroborating evidence documenting their risk. Some risks will be of concern to the public but insubstantial in actual level of threat but in a democracy agencies cannot ignore these distractions and must be seen to be responsive to public concerns.

One example is concern over "toxic mold", an issue now largely passed that attracted attention as a possible public health emergency from federal agencies in the US and Canada, although remains weak for the core concept of disease induced as a result of exposure to mold-derived toxins. (IOM, 2004) Another more historical example is concern over health effects associated with electromagnetic fields, which has lasted over two decades with little substantive evidence in the end for a major health effect. (Feychting *et al.*, 2005)

The relevance of this concept to the priorities of regulatory agencies is clear. Government agencies may use tools of risk anticipation to identify issues that are likely to become issues of public concern and media attention, while they are in evolution. Such issues in the recent past correctly identified "toxic mold", which suddenly and unexpectedly came to dominate the agenda of indoor air quality and environmental health in 2001.

The private sector may apply the principles of risk management for business purposes. One area in which risk management plays an obvious and key role is in product liability, including liability to workers who use the product on the job, and in environmental risk from introducing a new product or process. Here the risk management implications are clearer. Anticipating risks may also be key to the survival of firms in high-risk industries and to the ability of many more to operate in sensitive communities.

An example is the experience of the Monsanto Corporation (now owned by Bayer as its Crop Science subsidiary) with genetically modified foods. Whatever the actual level of risk, the public's concern caught the company by surprise and had highly negative ramifications. That Monsanto

was surprised and ill-prepared to deal with the public showed how poorly they understood the characteristics of the issue and underestimated the subjective human response. As aptly stated by the chief executive officer of Monsanto, Hendrik Verfaillie (Safford 2000):

> "Monsanto had focused so much attention on getting the technology right for our customer--the grower--that we didn't fully take into account the issues and concerns it raised for other people. We didn't understand that when it comes to a serious public concern, that the more you stand to make a profit in the marketplace, the less credibility you have in the marketplace of ideas. When we tried to explain the benefits, the science and the safety, we did not understand that our tone--our very approach--was seen as arrogant."

Monsanto's failure to anticipate the perception of risk that developed forced a corporate crisis that cost them dearly. Using the tests proposed, it was predictable that genetically-modified foods would be controversial because in one issue it combined concern about genetics, food safety, children, tampering with nature, introducing irreversible changes, and religious sensitivities, over humankind acting like the Creator. Indeed, "aversion to tampering with Nature" is now a quantifiable element in modeling risk perception. (Raimi *et al.*, 2020)

At the same time, there are hazards that present serious risks that, for all the reasons commonly taught as part of risk perception, are underappreciated. Household chemical exposures, involving chemicals such as chlorine bleach, are well below public awareness but present significant hazards. (Hattis *et al.*, 1991) Medical misadventures and injury represent a large class of hazards that have been markedly underappreciated until very recently, in part because of fragmentation of regulation. (IOM, 2004)

Risk anticipation presents a set of management issues different from risk assessment or risk management. If the magnitude of the risk is substantial, it is likely only to be recognized by a small technical group intimately familiar with its characteristics. In most cases the hazard will be unknown to the broader scientific community or the public. For example the 14 August 2003 power blackout around the Great Lakes in the United States was predicted years in advance by electric power experts but appreciated by

almost nobody outside the industry. (Lerner, 2003; Albert *et al.*, 2003). Table 1 presents a short list of examples of environmental health risks that are currently under investigation and for which evidence is inconclusive. Over the next few years, at least one of these issues is likely to emerge as a major public concern, but which it will be cannot now be predicted.

Table 1. Examples of early, emerging environmental health risks for which evidence is currently inconclusive:

- Environmental risks associated with hydrogen fuel
- Neurotoxicity and neurocognitive effects due to arsenic exposure
- Risk to consumers (rather than workers) of popcorn flavoring (diacetyl)
- Chronic health effects of low-level hydrogen sulfide exposure at levels below 10 ppm
- Health effects of microcystins (algal toxins) in drinking water
- Health risks associated with smoking water pipes
- Health risks associated with bisphenol compounds
- Nanomaterials (a cluster of issues that has yet to be disaggregated)

Criteria for Prioritizing Future Risk Issues

Risk anticipation can be systematized. A comprehensive theory of risk anticipation is beyond the scope of this paper. However, a demonstration of an empirical approach to the issue can be provided at this time.

A constructive approach to risk anticipation needs to prioritize hazards and to be informed by the realization that not every hazard is worth responding to. Risk anticipation can be systematized and may represent a new frontier in risk science studies. Risk management is constrained by resources and prioritization by decision makers is constrained by attention. An approach to risk anticipation that is practical, transparent, and systematized may help all parties prevent the next environmental crisis, or at least keep it manageable.

Some "emerging issues" become hot topics receiving public scrutiny and others do not. This is partly due to the real risk they represent, and the urgency of controlling exposure and risk, which are usually defined by experts. It is also partly because the public may perceive a risk or threat that the experts may or may not perceive.

Environmental risks are a subset of public issues characterized by technical detail and, almost always, insufficiency of sure knowledge. In the absence of reliable or complete information, and in the presence of great uncertainty over the implications, the public treats such issues as it does other issues of public debate and controversy, in which values and perceptions may play a greater role than facts. The same characteristics that attach to other controversial issues in society should therefore apply to environmental health risks.

The sociologist Talcott Parsons described the characteristics of "public issues", those problems perceived as worthy of general public debate and attention by governments and the concerned public (reference). Public issues have the following attributes:

- Affect many people;
- Have an effect over many classes and communities, not just a single group;
- Have a significant impact, thus were not trivial in their effects;
- Are amenable to control by concerted action.

The same characteristics apply to hazards that are likely to become celebrated risks and that require advance planning for risk management. They may be taken as a provisional set of features that predict the future emergence of an issue receiving limited attention into broader public debate.

Characteristics of those hazards that, in retrospect, became public issues are well known. The well-known factors described by Sandman and others (Covello and Sandman, 2001; Sandman, 1989, 1987; Slovic, 1987), such as outrage, dread, familiarity, effect on children, imposition as opposed to voluntary assumption of risk, persistence or irreversibility, and novelty can be applied in advance to assess new and emerging hazards. Also important are concepts of what constitutes pollution or contamination, what represents a perception of interference in nature and what products or pollutants are discordant with people's ideas of how the world should be.

An Exploratory Study

In 2000 a list of potentially important emerging issues in occupational health was developed by the author for internal use in a strategic planning exercise by the American College of Occupational and Environmental Medicine. Topics were identified from the Occupational-Environmental-Medicine List, which is a communication resource for the occupational health professions sponsored by the Association of Occupational and Environmental Clinics. The list serves about 1500 professionals and has postings several times per day, often featuring back-and-forth discussion and reflects current discussion within an expert group that regularly discusses risk issues, the occupational health community. Table 2 presents a list of selected topics which featured recurrent appearance in long strings of messages on the same or a similar topic.

Table 2. Emerging Issues in Occupational Health identified in the Year 2000 from the on-line Occupational and Environmental Medicine List.

Occupational health management issues

Back pain
Diagnostic precision
Firefighters*
Latex allergy*
Metal cutting fluids*
Medical Review Officer procedures (drug testing under US law)
Multiple chemical sensitivity
Stress*
Treatment protocols

Policy issues

Confidentiality* (driven by new US federal legislation)
Ergonomics standard* (driven by a controversial OSHA regulation)
Ethics
Phthalates (health effects associated with)

Organized medicine and specialty affairs

Appropriate clinic staffing levels
Affairs of a particular international organization and its officers
State licensure issues

*Issues that actually did emerge over the next two years as important "public issues" broadly discussed in the occupational health professional community.

In 2002 the issues were reevaluated for emergence as a public issue. Equally interesting, however, were the emerging, hot topics from 2000 that did not make it to widespread discussion. The Topics from Table 2 had the following status in 2002:

- Issues that emerged as a result of circumstances, which often could not have been foreseen in 2000:
    - Firefighters' health (largely as a result of the events of 11 September 2001 and the experience of New York firefighters in the World Trade Center catastrophe)
    - Ergonomics (driven by a draft ergonomic standard proposed by the Occupational Health and Safety Administration)
    - Confidentiality (driven by new US legislation called "HIPAA" and US Medicare reforms)
    - Stress (already prominent as an issue and perceived as a threat to public, stress became even more visible due to new research findings and growing expense of claims for stress-related in the workers' compensation system)
- Issues that developed to become major issues within occupational health on their own momentum (although not as widely recognized as Parson's "public" issues):
    - Metal working fluids (a widespread hazard in industry for which new information was becoming available)
    - Latex allergy (a widespread hazard in the healthcare sector, therefore of concern to the public)
    - Treatment protocols (as a consequence of a general movement in workers' compensation toward evidence-based guidelines)

- Issues that did not emerge or demonstrably increase in public concern.
    - Phthalates and medical safety (which, although it fulfilled Parson's other criteria, may have been perceived as insufficient in magnitude of risk)
    - Back pain (already heavily discussed but admitting of no obvious new collective approach)
    - Ethics (always an issue in medicine but in the field of occupational medicine there were no major developments to drive it)
    - "Multiple chemical sensitivity" (an unproven theory of disease that seemed to be running the course in public acceptance)
    - Attacks on a specific international organization and its leaders (too narrow to be of general interest and the allegations were refuted)
    - State licensure issues (too narrow and little can be done without legislation that does not appear forthcoming any time soon).
    - Staffing levels (too narrow), diagnostic precision (not amenable to collective action?)
    - Drug testing procedures (applies to a relatively narrow group for which there is not much sympathy).

Thus, Parson's criteria appear to explain why particular issues reached public discussion in the United States broadly and in the field of occupational health while others did not.

Empirical Validation

Another demonstration of the viability of a systematic approach to risk anticipation was an unexpected outcome of a study done for another purpose. (Guidotti, and Herz, 2002) A schema for identifying emerging issues and setting priorities among competing issues was developed for a Canadian federal-provincial government subcommittee with responsibility for prioritizing environmental risks to health. The committee had been criticized by its parent council for not doing setting priorities on a strictly scientific basis. The chairs of the subcommittee wanted to show that the

social factors they had taken into account were proper considerations, not political, and wanted to develop a transparent system to show that they were being systematic about it. It succeeded in doing so, although the committee was disbanded soon after for other reasons.

The objective of the project was a prioritization system that would demonstrate responsiveness to the various agencies' mandates, flexibility, discriminatory power, transparency, and accountability, mechanisms for dealing with uncertainty, and robustness. Simple scoring systems tended to "clump" priorities in a middle range and had not been satisfactory. The protocol ultimately developed (Guidotti and Herz, 2002) required assignment to categories and calculations in five steps, taking into account the mandate of the agencies concerned, the magnitude of the worst likely effect, the distribution of the hazard or impact across Canada, and whether the issue represented a single hazard, a set of exposure-related problems, or a generic problem. The system had the advantages of good resolution of issues and easy adaptation by simple changes in the weighting scale. It also tended to reduce political distortions on setting priorities because the technical parameters were to have been agreed upon in advance. However, it was unwieldy and overly complicated for routine use, requiring skilled staff to implement. In the event, it was never used in practice. Even so, the exercise proved very revealing.

The protocol was applied to a list of issues currently before the committee as a test. Interestingly, the system identified three issues that later unexpectedly did come to prominence, in addition to three issues that were already prominent. The three issues for which the system seemed to predict future visibility were:

- Health impact assessment guidelines foreshadowed the later emphasis on biomonitoring guidelines within Health Canada.
- Drinking water concerns foreshadowed the impact of events yet to come, particularly Walkerton, after which the issue dominated the environmental health agenda in Canada for several years.
- Mold-related illness, which subsequently came from obscurity as an issue to dominate toxic tort and construction defect litigation in the United States and Canada. This was a wholly unexpected and dramatic result.

Several lessons were learned from the exercise. The system needed to be much simpler, both for ease of technical implementation and for transparency. The system was based on an assessment of risk, not perception of risk. Thus, it remained at heart an expert system, not a consensual method for risk comparison. The factor of outrage was missing, precluding it as a viable system for anticipating political and public interest.

Although this early effort was not practical, it was clear that even this preliminary device could predict the emergence of certain issues as public concerns. Until such time as a validated instrument is developed, the best approach may be to use the same list of characteristics that are incorporated into risk communication guidelines, in the form of a checklist against which to rate issues and hazards. (Table 3)

Factor	Effect on Public Perception*	Check list
Characteristics Associated with Risk Perception		
Outrage	–	
Catastrophic potential	–	
Impact on children, future generations	–	
Victim identity (put a face to the number)	–	
Dread outcome (e.g. cancer)	–	
Media attention	–	
Inequity, environmental justice issues	–	
Scientific uncertainty	–	
Familiarity	+	
Trust	+	
Benefit to community associated with risk	+	

No human agency involved	+	
Voluntarily assumed	+	
Transparent and accountable management	+	
Potentially controllable by those subject to exposure	+	
Characteristics Associated with Public Issues		
Affects a large or diverse group; not confined to a narrow interest group	–	
Amenable to collective action	–	
Sufficient impact, in terms of magnitude of risk	–	
Sufficient impact, in terms of number affected	–	

Table 3. Draft instrument for a risk anticipation instrument based on characteristics of risk issues.
* Key: + = Positive perception, *i.e.* reduces public concern, – = negative impact, *i.e.* increases public concern.

The Way Forward

A useful application of risk anticipation would identify two relevant outcomes: potentially significant hazards that might otherwise be overlooked, and hazards with a high probability of provoking public concern and therefore emerging as a public issue.

An agenda for research anticipation research may be guided by the following questions:

- Is it possible to "score" the characteristics of a hazard to predict which will become issues of public concern? This involves quantifying the impact of various factors.
- What is the natural history of novel hazards that do not emerge as public issues?
- How do the factors work in different communities and at different times in, for example, the economic cycle?
- What is the role of the media in bringing an obscure hazard to prominence?

- Is there a life cycle to public issues such that they peak at a predictable time in their development?
- How does the public form its impressions of hazards when media coverage is incomplete?

Development of an instrument for predicting the likelihood of emergence of an issue might begin with a list of characteristics such as presented in Table 3. The instrument may be refined by assigning weights to them, perhaps based on empirical studies of the predictive value of the items. Retrospective efforts to validate such instruments are likely to be contaminated or biased because the fate of the issue is known. Since such research necessarily requires the elapse of time before the fate of an issue becomes known, prospective studies cannot be done quickly. Such studies also require a more rigorous operating criterion for when an issue meets the definition of a public issue.

Risk anticipation represents a new approach to the early identification of issues likely to consume the attention of the public, experts and risk managers alike. The approach may have great practical utility for public agencies and the private sector. Work to date has been rudimentary but promising. More sophisticated instruments and methods are well within reach.

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Bio

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Acoustical Society of America	Paul Arveson
American/International Association of Dental Research	J. Terrell Hoffeld
American Association of Physics Teachers, Chesapeake Section	Frank R. Haig, S. J.
American Astronomical Society	Sethanne Howard
American Fisheries Society	Lee Benaka
American Institute of Aeronautics and Astronautics	David W. Brandt
American Institute of Mining, Metallurgy & Exploration	E. Lee Bray
American Meteorological Society	Vacant
American Nuclear Society	Charles Martin
American Phytopathological Society	Vacant
American Society for Cybernetics	Stuart Umpleby
American Society for Microbiology	Vacant
American Society of Civil Engineers	Vacant
American Society of Mechanical Engineers	Daniel J. Vavrick
American Society of Plant Physiology	Mark Holland
Anthropological Society of Washington	Vacant
ASM International	Toni Marechaux
Association for Women in Science	Jodi Wesemann
Association for Computing Machinery	Vacant
Association for Science, Technology, and Innovation	F. Douglas Witherspoon
Association of Information Technology Professionals	Vacant
Biological Society of Washington	Vacant
Botanical Society of Washington	Chris Puttock
Capital Area Food Protection Association	Keith Lempel
Chemical Society of Washington	Vacant
District of Columbia Institute of Chemists	Vacant
Eastern Sociological Society	Ronald W. Mandersheid
Electrochemical Society	Vacant
Entomological Society of Washington	Vacant
Geological Society of Washington	Jeff Plescia Jurate Landwehr
Historical Society of Washington DC	Vacant
Human Factors and Ergonomics Society	Gerald Krueger

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Delegates to the Washington Academy of Sciences Representing Affiliated Scientific Societies

(continued from previous page)

Institute of Electrical and Electronics Engineers, Washington Section	Richard Hill
Institute of Food Technologies, Washington DC Section	Taylor Wallace
Institute of Industrial Engineers, National Capital Chapter	Neal F. Schmeidler
International Association for Dental Research, American Section	Christopher Fox
International Society for the Systems Sciences	Vacant
International Society of Automation, Baltimore Washington Section	Richard Sommerfield
Instrument Society of America	Hank Hegner
Marine Technology Society	Jake Sobin
Maryland Native Plant Society	Vacant
Mathematical Association of America, Maryland-District of Columbia-Virginia Section	John Hamman
Medical Society of the District of Columbia	Julian Craig
National Capital Area Skeptics	Vacant
National Capital Astronomers	Jay H. Miller
National Geographic Society	Vacant
Optical Society of America, National Capital Section	Jim Heaney
Pest Science Society of America	Vacant
Philosophical Society of Washington	Michael P. Cohen
Society for Experimental Biology and Medicine	Vacant
Society of American Foresters, National Capital Society	Marilyn Buford
Society of American Military Engineers, Washington DC Post	Vacant
Society of Manufacturing Engineers, Washington DC Chapter	Vacant
Society of Mining, Metallurgy, and Exploration, Inc., Washington DC Section	E. Lee Bray
Soil and Water Conservation Society, National Capital Chapter	Erika Larsen
Technology Transfer Society, Washington Area Chapter	Richard Leshuk
Virginia Native Plant Society, Potomac Chapter	Alan Ford
Washington DC Chapter of the Institute for Operations Research and the Management Sciences (WINFORMS)	Meagan Pitluck-Schmitt
Washington Evolutionary Systems Society	Vacant
Washington History of Science Club	Albert G. Gluckman
Washington Paint Technology Group	Vacant
Washington Society of Engineers	Alvin Reiner
Washington Society for the History of Medicine	Alain Touwaide
Washington Statistical Society	Michael P. Cohen
World Future Society, National Capital Region Chapter	Jim Honig

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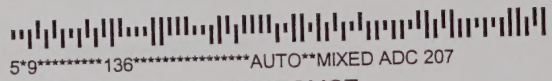

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